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16. Abstract

The article consists of a brief review of the history of recording of nystagmus, and a survey of the literature on the subject.

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Candidate of Medical Sciences K. S. Tanchev

Electronystagmography (ENG) is one of the modern methods for objective recording of nystagmus, its quantitative and qualitative assessment. Recently ENG has been used more and more often in clinical practice. Regardless of this, a number of questions in the technique of its use, and in evaluating different parameters of the nystagmogram have still not been defined more accurately (N. S. Blagoveshchenskaya, 1968; A. Ye. Kurashvili, V. I. Babiyak, 1970; Bochenek, 1963; Jongkees, Philipszoon, 1964, et al.). /82*

The first experiments to record nystagmus were made by physiologists in an experiment on animals. In 1881 Hogyes recorded nystagmus with the help of a needle stuck into the animal's eye. V. I. Voyachek (1908) and Buys (1909) for the first time developed clinical methods of nystagmography. Even before them, Purkinie (1820) and Breuer (1874) studied spontaneous nystagmus by palpation, with closed eyes. Original experiments were conducted by the Krakow ophthalmologist Majewski (1917) who with the help of the modified method of Boyachek was able to record rotary eye movements. In 1909-1912 nystagmography was used in the clinic. It was used by Barani, Bartel's, Gredenigo, Vitmaak and others (cited in Bochenek, 1963).

There are many different methods for recording eyeball movement. M. V. Kulikova (cited in N. S. Blagoveshchenskaya, 1968) found in the

*Numbers in margin indicate pagination in original foreign text.

accessible literature 40 methods and apparatus for conducting nystagmography and separated them into five groups: photographic or optic; nystagmography with pneumatic transmission of eye movement; mechanical method; kymographic recording and nystagmography for recording eye movement with the help of electricity.

Torok et al. (1951) classify all the methods into mechanical, photographic and electrical. Of them electronystagmography, recording of changes in the corneoretinal potential has been most widely used. It is convenient and does not have a traumatizing effect on the eyeballs. Aschan et al. (1956), Hamersma (1957), Hennebert (1960), Jung (1953), Megighian (1959) and Stahle (1958) have described in detail the history of nystagmography. Meyers introduced the term ENG in 1929. ENG is based on the difference in biopotentials between the cornea (+) and the retina (-), that is changed depending on the angle of deviation of the eyeballs.

Many works have been published on the ENG question, especially in the last 20-30 years (I. A. Sklyut, 1957; S. S. Markaryan, 1958; N. S. Khrappo, 1964; N. S. Blagoveshchenskaya, 1964, 1968; I. Ya. Kalinovskaya, Yu. S. Yusevich, 1964; Ye. A. Kupryashkin, 1966; Kalinovskaya, 1973; V. Z. Kapranov, 1976; I. F. Kandurov et al., 1976; V. G. Bazarov, 1977; Montandon, Monnier, 1951; Mittermaier et al., 1952; Henriksson, 1956; Jongkees, Philipszoon, 1964; Montandon, 1969; Ledoux et al., 1974; Dix, 1976; Minnigerode et al., 1977, and others).

The corneoretinal potentials were discovered back in 1849 by the German physiologist Du Bois Reymond. For a long time they were given an incorrect explanation, linking their action to the eye musculature. The corneoretinal potential develops due to the difference in intensity of the biochemical processes in the cornea and the retina (in the cornea--weak, and in the retina--intensive). The eyeball functions as a rotating electrical dipole. The electrical axis of the eye coincides with the visual. A change in the position of the visual line in relation to the horizontal or sagittal plane (as occurs in nystagmus) results in a difference in /83 the potentials in the periocular tissues that can be intensified and recorded in the form of characteristic oscillograms. The quantitative indices of the motor reactions of the eyes consist of two parameters: angle of deviation of the eyeballs (amplitude) and time during which the eyeballs are deviated at this angle. The polarity of the corneoretinal potential makes it possible to determine the direction of deviation of the eyeballs, and to establish the vectoriality of the recordable eye movement reactions. The corneoretinal potentials are almost the same in invertebrates and vertebrates (about 10 mV) and are changing almost constantly. Miles (1940) studied the potentials of the human eye and established that they are 2-7 mV.

The corneoretinal potentials change during eye movement depending on the illumination, medication background, period of the day, general condition of the organism (the potentials increase to 100 mV under the influence of mental stress) and other factors (Pfaltz, 1974). With prolonged adaptation the potential is reduced, therefore it is necessary to frequenctly calibrate (before and after conducting the study, and during recording of the spontaneous nystagmus--every 5 min.). It follows from this that during calibration of nystagmus and subsequent analysis of the electronystagmograms we need to keep in mind these influences, and the illumination of the room and test-objects must be standard.

The researchers are faced with solving many tasks in the search for the most adequate method of mathematical analysis of the dynamics of the nystagmic reaction. A number of important studies have been made in this direction by A. S. Kleshchev, M. M. Levashov (1969), T. A. Nalimova, M. M. Levashov (1968), as well as Schmid et al. (1971).

The corneoretinal potential rises linearly with an increase in the angle of deviation of the eyeball from the position of rest.

It is registered with the help of electrodes and is amplified by electronic amplifiers, from which it enters the recording devices, oscillographs (that produce visual or graphic recording). To record the horizontal movement of the eyeballs the electrodes are attached directly to the external angles of the eyes (three electrodes are needed, one of which is placed in the middle of the forehead--the neutral electrode), while for recording of vertical eye movements--above and under one or two eyes, i.e., at the site of the vertical axis that passes throught the center of the pupil (N. S. Blagoveshchenskaya, 1968; A. Ye. Kurashvili, V. I. Babiyak, 1970; V. G. Bazarov and A. I. Rozkladka, 1975; Greiner et al., 1969, and others). Rotary nystagmus is recorded with the help of the photoelectronystagmographic method (PENG), in which one can record both transverse and vertical nystagmus, therefore it is considered a supplement to ENG. The sensitivity of PENG is 10 times higher than the ENG. Two photo elements are placed nasally and temporally from the eye. They are directed to the boundary that connects the cornea and the sclera. A definite source concentrates infrared rays towards the center of the eye. Depending on the direction of deviation of the eye, different shifts are obtained in the two photo elements. Here artifacts are avoided, i.e., shifts from nictitation, movements of the muscles in the face, head, neck and others, and from a decrease in the corneoretinal potential (Torok et al., 1951; Pfaltz, Richter, 1955, 1956; Hennebert, 1960; Greiner et al., 1969; Pfaltz, 1970, and others). Vector nystagmography is the recording of potentials from one vertical and one horizontal electrode. This technique is still in the development stage.

Modern ENG-apparatus with automatic processing of the nystagmus recording has not yet been unified and has not been standardized. It is very expensive and is not accessible for practical use; it is mainly employed in scientific research work. Nystagmus is most often recorded on electronystagmographs, EEG- and EKG-apparatus with certain additional reorganization. Depending on the amplifiers used in ENG one can define two main types of them: direct current

(DC amplifier) and alternating current (AC amplifier). The latter are used more often since they do not record additional potentials of the musculature, skin and others. An important characteristic feature of the amplifier is the time constant. It equals the time during which the voltage drops to 1/e part (about 37% of its initial amount). The ENG uses a compromise time constant, i.e., it is not very small (to avoid curves in the slow phase of the nystagmus) or very big (in order to avoid considerable deformations in the fast eye movements). Different authors give different time constants that vary from 0.05 (Arnold, 1959) to 10 s (Mc Lay, Madigan, Ormerod, 1958). Aschan et al. (1956) use the time constant of 3 s, Stahle (1958)--1.7 s, Kornhubert (1966)--2 s, Fluur (1970)--from 1 to 2 s, and we--0.8 s and 2.5 s.

Of great importance in the ENG is the appropriate selection and installation of the electrodes. As Aschan stresses (1960), a large number of the difficulties are linked to insufficient fixing of the electrodes, disruption of the conductors and others. The electrode surfaces are primarily used. They must fit the skin well and not move during the study. It is necessary to place the electrode as close as possible to the eyeballs, since the potentials of the electrical field rapidly change the farther from its center. At this site the corneoretinal potenials surpass the other bioelectrical potentials, and therefore recording of eye movements is possible /84 even with amplitude of 1°. The majority of authors (Aschan et al., 1956; Stahle, 1958; Bochenek, 1963, 1977; N. S. Blagoveshchenskaya, 1968; V. G. Bazarov, A. I. Rozkladka, 1975) attach the electrodes such that the movement of the eyes to the right in a horizontal plane and upwards in a vertical is recorded above the iso-electrical line, and to the left and downwards--under it (this unification was adopted at the Second International Symposium on Vestibulology in Geneva in 1960). It is necessary to record the nystagmus in a screened and sound-proofed chamber with closed eyes of the subject, but in certain cases the study can be conducted also with open eyes (N. S. Blagoveshchenskaya, 1968).

Another important component of the ENG is the writing element. It can be the cause of distortion in the recording, as a consequence of its lightness and the resonance phenomenon. The rate of movement of the tape is important; the configuration of the recording depends on it to a certain degree. We record at a rate of 7.5 or 15 cm/s, Bochenek (1977)--0.5-1.5 cm/s, Mittermaier (1965), Kornhubert (1966), Albert (1969) suggest recording recording at a rate of 1.0 cm/s. The higher or lower rate is used depending on the desire to record greater or lesser details, mainly in the zone of the slow phase of the nystagmus.

Calibration of the deviation of the eyeballs is important for computing the recording of the main qualities of nystagmus. This is a mandatory condition in reading the nystagmogram, since intensity of the electrical field of the eye is individual and can change in the same person during the study. Lengthy studies require repetition of the calibration. The latter is based on the rule of Mowrer et al. (1936) that states, that changes in the intensity of the electrical field of the eye are directly proportional to the angular movement of the eye (for angles that do not exceed 20°). The purpose of the calibration is to determine the scale of the amplitude, i.e., to record the amplitude measured in millimeters, that meets the predetermined angular movement of the eye in degrees. A linear relationship exists between these two amounts (Mowrer et al., 1936). For calibration it is necessary to place a device with 3-5 distinctive objects at the subject's eye level, for example, with colored lamps (V. G. Bazarov, A. I. Rozkladka, 1974). The distance between individual objects must be strictly predetermined. Usually three distinctive objects are placed in a horizontal plane, and two others--in a vertical. When the eyes are moved from one source to the other one can define the angle at which eye movement occurs. Amplification of the nystagmograph is selected such that 1° deviation of the eye meets the deviation of the writing element by 1 or 2 mm from the isoline. Bochenek (1963) records no less than 5 eye deviations between the two objects. The amplitude is computed as the average arithmetical of five deviations.

Nystagmus (spontaneous, position, caloric, post-rotational and optokinetic) defined both visually and with the ENG has the following parameters: direction, amplitude of nystagmic reaction (summary and average), duration of nystagmus, frequency, angular rate, and others (N. S. Blagoveshchenskaya, 1968; A. Ye. Kurashvili, V. I. Babiyak, 1970; V. G. Bazarov, 1977; Bochenek, 1963, and others). On the electronystagmogram the nystagmus is recorded in the form of a curve consisting of a number of projections. Each of them corresponds to one nystagmic jolt. In order to interpret the nystagmogram different methods are used, but still there is no single opinion on which of them is the best. Aschan, Bergstedt, Stahle (1956), Stahle (1958) focus a lot of attention on the duration of nystagmus, the number of nystagmic beats, the general amplitude and maximum rate of the slow phase of nystagmus. In the opinion of Stahle (1956), the duration of nystagmus is changed least of all as compared to its other qualities. Mittermaier (1954, 1965) attributes importance mainly to the duration of nystagmus, number of beats and general amplitude. Jongkees, Philipszoon (1964) focus attention on the maximum rate of the slow phase of nystagmus, rate, number of positions in which nystagmus appears.

Vestibular nystagmus consists of a slow and fast phase. The latter determines the direction of nystagmus. Different direction of nystagmus has a different recording on the electronystagmogram depending on the connection of the electrodes. From the electronystagmogram one can clearly determine the direction of the horizontal, vertical, and diagonal nystagmus, but not the converging and rotary (N. S. Blagoveshchenskaya, 1968) The vectoriality of nystagmus has great importance in diagnosing different diseases of the vestibular apparatus and systems linked to it. According to the direction of nystagmus one judges the localization and dynamics of the pathological process (A. Ye. Kurashvili, V. I. Babiyak, 1970; K. S. Tanchev, 1976, and others).

The end of the nystagmic reaction is defined from the disappearance of the typical nystagmic cycles that follow in a certain rhythmic sequence and have the same direction. Certain authors (Aschan, Bergstedt, Stahle, 1956; Jongkees, Philipszoon, 1964; Mittermaier, 1965, and others) suggest that the end of the reaction be considered the first nystagmic beat in the opposite direction, i.e., the first beat of the so-called second nystagmic phase or inverse movement of the fast component. A. Ye. Kurashvili and V. I. Babiyak (1970) prove that at the end of the reaction there can be several such beats with typical nystagmic cycles. K. L. Khilov (1969) suggests defining the end of the nystagmic reaction by the so-called auction method according to which the last nystagmic movement is assumed to /85
be the nystagmus after which a new one does not appear for 3 s.

The amplitude of nystagmus is the angle at which the eyes are deviated during the nystagmic beat. The amplitude and frequency of nystagmus are influenced by the extralabyrinth factors (N. S. Blagoveshchenskaya, 1968; Bochenek, 1963). The age of the subject also is important (Arslan, 1957; Nicolai, 1961; Rossberg, 1964). At age 20-40, after strong rotational stimuli higher and stronger reactions in amplitude are observed than at age 60-80. In the opinion of A. Ye. Kurashvili and V. I. Babiyak (1970) amplitude is one of the most important indices for the degree of excitability of the vestibular apparatus. Great amplitude is inherent to individuals with increased excitability of the vestibular apparatus and patients suffering from certain forms of vestibulopathy.

If one knows the calibration amplitude and its standard angle (it roughly equals 20°), then one can determine the amplitude of one nystagmus cycle from the following formula:

$$x_1 = 20° \frac{a}{A} \text{ degrees},$$

where x_1--amplitude of one nystagmic cycle; a--amplitude of studied nystagmic cycle in millimeters; A--amplitude of calibration oscillation in millimeters, corresponding to the standard angle equal to 20°.

The frequency of nystagmus can be expressed in hertz and computed from the formula:

$$F = \frac{n}{t},$$

where n--number of nystagmic cycles, t--reaction time in seconds.

A. Ye. Kurashvili, V. I. Babiyak suggest computing the frequency only from the first two-thirds of the reaction, while N. S. Blagoveshchenskaya (1968)--every 10 s during the caloric test. A number of authors (Stahle, 1956; Bochenek, 1977, and others) recommend computing the frequency in the space of 10 s during the culmination of the reaction.

Angular velocity of nystagmus is determined from the slow phase, since it precisely reflects the functional condition of the vestibular analyzer (Mittermaier et al., 1952; Henriksson, 1955, 1956; Aschan, Bergstedt, Stahle, 1956; Dohlman, 1960, and others). Different methods exist for computing the angular velocity of the slow phase of nystagmus (A. Ye. Kurashvili, V. I. Babiyak, 1970; V. G. Bazarov, A. I. Rozkladka, 1976; Bochenek, 1977; Jongkees, Philipszoon, 1964, and others). This is done from certain formulas, tables, or with the the help of different attachments. Usually the average angular velocity of the slow phase of nystagmus is computed in a 10-20-second period of the maximum reaction (V. G. Bazarov, A. I. Rozkladka, 1976). Ye. A. Kupryashkin (1966) defines it from the size of the nystagmus amplitude and frequency. N. S. Blagoveshchenskaya (1968) attributes great importance to the numerical correlation between the duration of the fast and slow phases of nystagmus, assuming that the average rate of eye movement in the slow phase of nystagmus changes not only during the caloric reaction, but even during one nystagmic cycle.

The separately taken aforementioned characteristics of nystagmus cannot completely and precisely characterize it. Therefore, certain authors take several nystagmic parameters and obtain a more accurate evaluation of the whole reaction. Thus, for example, Ohm (1939) suggests determining the energy of nystagmus depending on the indices of the total amplitude and frequency, i.e., the greater the amplitude of the nystagmic beats and the greater their frequency, the more energy the reaction has. Hopman (1936), Mittermaier, Christian (1954) believe that the maximum reaction after the caloric stimulus occurs in the period of 30-60 s from the beginning of stimuluation, and therefore one can establish a quantitative relationship between the strength of the caloric stimulation and the nystagmic reaction. Mittermaier (1954) suggests evaluating the results by graphic illustration of the data on a coordinate system, where individual time intervals are plotted on the X-axis, and the total amplitude of these intervals on the Y-axis. Stahle (1958) and Aschan et al. (1956) plot the time in minutes on the X-axis, and the intensity of nystagmus on the Y-axis (the amplitude of the eye movements in angular degrees). A preliminary recording is made of the spontaneous nystagmus. As a consequence of the listed difficulties and contradictions, in recent years the results of electronystagmograms were analyzed and individual parameters of the nystagmus were computed automatically with the use of computer systems (Ghilardi et al., 1974; Anzaldi, Mira, 1975, and others).

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